FIELD EVALUATION OF ANHYDROUS AMMONIA MANIFOLD PERFORMANCE

P. M. Boyd, H. M. Hanna, J. L. Baker, T. S. Colvin

ABSTRACT. *Experiments conducted between August 1999 and April 2002 evaluated anhydrous ammonia manifold distribution during field application at 84− and 168−kg N/ha (75− and 150−lb N/acre) application rates. Multiple manifolds including the conventional (Continental NH_3 Model 3497, Dallas, Tex.), Vertical−Dam (Continental NH_3 Dallas, Tex.), Rotaflow™(H.I. Fraser Pty Ltd, Sydney, Australia), Equa−flow™(PGI International, Houston, Tex.), FD−1200 prototype (CDS John Blue Co., Huntsville, Ala.), and the Impellicone prototype manifold were tested. Temperature and pressure data were collected along the flow path.*

Results showed high distribution variation by the conventional manifold at both application rates, with average coefficient of variation (CV) values in excess of 16%. At the 84−kg N/ha (75−lb N/acre) rate, all other manifolds tested had significantly lower application variation (α = 0.05). At the 168−kg N/ha (150−lb N/acre) rate, the conventional manifold grouped statistically with the Vertical−Dam with a corn ring and the FD−1200 prototype, producing CV values between 9.5% and 16.2%. All other manifolds had significantly lower application variation. The Impellicone, Rotaflow ™, and Equa−flow ™, manifolds performed with the lowest measured variation at both rates, yielding best performance at the 168−kg N/ha (150−lb N/acre) rate with CV in the 6% range.

Analysis of recorded temperature and pressure data indicate that NH_3 flowing through the system very closely follows the saturation line and acts as a saturated mixture. Predictions of NH_3 quality based on calculations of an ideal adiabatic mixture are supported by this result. Investigation for correlation between CV, air temperature, and percent of volume in the vapor phase of NH_3 resulted in only a visual trend that may suggest a reduction in CV with lower percent of volume in the vapor phase.

Results suggest that replacement of a conventional manifold with a Vertical−Dam manifold or any of the other manifolds tested could reduce application variation between 7.0% and 16.5% at 84 kg N/ha (75 lb N/acre) and 1.0% and 10.2% at 168 kg N/ha (150 lb N/acre). This change could reduce application rate by eliminating the need for over−application to compensate for variations.

Keywords. *Anhydrous ammonia, Manifold, NH_3, Nitrogen, Fertilizer, Distribution, Application variation.*

Variations in application rates with anhydrous ammonia (NH_3) have resulted in concerns about possible water quality issues associated with over application of nitrogen (N). Jaynes et al. (2001) found that of three rates of N application ranging from 57 to 202 kg N/ha (51 to 180 lb N/acre), only for the lowest application rate after soybeans in a corn/soybean rotation did the concentrations in drainage water not exceed the USEPA limit of 10 mg NO_3−N/L. For all years of the study, the mass of N lost at the high rate was significantly higher than the amount lost at the two lower rates. Karlen et al. (1998) found that during a four−year study in Iowa, over a wide range of N application rates, tillage practices, and application times, 50% of the applied N was available for leaching, denitrification, and/or NH_3 volatilization. Dinnes et al. (2002) suggested that strategies for reducing NO_3−N loss through subsurface drainage include the correct timing of N application at appropriate rates, and optimizing N application techniques.

Hedman and Turner (1954), after evaluation of NH_3 regulator and flow−controlling devices, noted that there was room for greater improvement in distributor (manifold) performance than could be achieved with improved total flow control. Morgahan (1980) concluded that evaluating NH_3 applicator performance by changes in field tank weight was not adequate for research work and suggested that the distribution of NH_3 among outlets be checked.

Hanna et al. (2002) found that when comparing the Vertical−Dam manifold to the conventional manifold, port−to−port variability was less for the Vertical−Dam at the 56−kg N/ha (50−lb N/ha) application rate but produced similar variability at the 112− and 168−kg N/ha (100− and 150−lb N/acre) rates. NH_3 exiting individual ports on the manifold typically varied 10% to 20% from the mean application rate, with the highest port flow 150% to 250% of

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the lowest port flow. Boyd et al. (2000) found improved performance with the Vertical−Dam over the conventional manifold while the Rotaflow™ manifold performed very well, with coefficient of variation (CV) values between 5% and 7% percent. Schrock et al. (2001) tested conventional and Vertical−Dam manifolds for distribution variation. Results showed a lower CV for the conventional manifold with a bottom inlet than a top inlet. The use of smaller diameter manifold hose barbs resulted in higher pressure with the conventional manifold but did not noticeably affect uniformity of distribution. Schrock et al. (2001) also investigated trends between CV and percent vapor, specific volume, inlet velocity, manifold pressure, and knife tube pressure. Only a trend between inlet velocity and CV was observed when small diameter hose barbs were used with the Vertical−Dam or top inlet conventional manifold. Kranz et al. (1994) suggested that metering accuracy to individual knives is improved by minimizing the amount of NH_3 vapor in the manifold. They recommended improving distribution by limiting the outlet orifice size at the manifold to increase back pressure at the manifold. The knife−to−knife outlet variation was difficult to measure and they suggested the only way to accurately determine distribution uniformity among knives was to do a water−can test.

In an attempt to calculate the flow rate of NH_3 as it passed through the system, Kocher et al. (2001) made the assumption that NH_3 followed the liquid−vapor saturation line as its pressure dropped through the system. Unfortunately, neither model used, based on the first and second laws of thermodynamics, fit the data well. Reasons for lack of fit were hypothesized as (a) the simple thermodynamic models did not adequately describe the behavior of the NH_3 flow in the system, and/or (b) measurement error. Failure of these models did not disprove the assumption of saturation.

Based on this past research, the following objectives were established for this study:

- To determine the ability of the commonly available conventional and Vertical−Dam manifolds to uniformly distribute NH_3 at the application knife during field application.
- To determine the ability of other manifold designs available at the time of the research to uniformly distribute NH_3 during field application.
- To design and evaluate a new manifold incorporating knowledge gathered in this research to further reduce variation during field application.
- To examine any correlation between NH_3 quality, temperature effects, and application variation.

Materials and Methods

Seven experiments were conducted between August 1999 and April 2002 to evaluate manifold distribution uniformity of NH_3 during field application. The experiments were completed on fields of the Iowa State University Agronomy and Agricultural Engineering Research Center near Boone, Iowa. Each experiment compared distribution of NH_3 manifolds by measuring the amount of NH_3 exiting each manifold outlet during a fixed application time.

Application rates selected were 84 and 168 kg N/ha (75 and 150 lb N/acre). Applicator travel speed was 8 km/h (5 mph). Test plots were 64 m (210 ft) long. Collection times were adjusted based on the application rate to collect an anticipated average of 0.3 to 0.5 kg (0.7 to 1.1 lb) of NH_3 from each knife. A detailed description of the test equipment and procedures can be found in Boyd (2002). A three−point mounted NH_3 applicator (DMI model 3250, Goodfield, Ill.) was configured for application by up to 11 knives (fig. 1). The NH_3 distribution system of the applicator was modified by inserting a valved pipe tee connection in each distribution line downstream from the distribution manifold to temporarily redirect NH_3 flow to collection containers. All flow lengths were kept equal so any pressure change due to control valves would cause the same effect on all outlets. This modification, in conjunction with an air−actuated system to switch flow direction in the valves, allowed for short−term collection of NH_3 in water within plastic buckets while the applicator was moving through the field.

The procedure for completing a test run included: loading the toolbar with an empty set of buckets, cooling the distribution system by injecting NH_3 into the ground, switching the valves to redirect flow into the collection buckets for 12 to 26 s depending on application rate, returning flow to the injection knives, and finally bleeding the system to ensure safety of persons unloading the buckets. Appropriate safety measures were followed in handling NH_3 collection buckets and while operating the equipment in the field.

Manifolds Tested

To test manifolds during a limited set of temperature and field conditions, the number of manifold configurations tested for each experiment was limited to six. Each manifold was operated three times at two application rates during the given experiment.

The August 1999 experiment compared conventional, Vertical−Dam and Cold−flo® manifold designs using both 7− and 11−outlet manifold configurations. The conventional manifold (Continental NH_3 model 3497, Dallas, Tex.) had space for 14 outlets with 9.5−mm (0.38−in.) female pipe thread (FPT) connections. Hose barbs that were 9.5−mm (0.38−in.) outside diameter and 7.1−mm (0.28−in.) inside diameter were evenly spaced in the outlets and the remaining outlets were plugged. This procedure was applied to all manifolds tested unless otherwise noted. Flow entered the conventional manifold directly from below via a 25.4−mm (1.0−in.) diameter, 254−mm (10.0−in.) long steel pipe nipple.

The Vertical−Dam manifold (Continental NH_3 Products, Dallas, Tex.) used either 7− or 11−outlet distribution rings and manifold housings suggested by the manufacturer for

Figure 1. NH_3 applicator used for all experiments.

each distribution rate. For the 84−kg N/ha (75−lb N/acre) application rate, a MVD housing was used with a SM:12" = 165#N/acre ring. For the 168−kg N/ha (150−lb N/acre) application rate a SVD−01 housing with an R−152 cotton ring was used. The MVD housing and SM ring were also evaluated at the 168−kg N/ha (150−lb N/acre) application rate. Although this application method is not recommended by the manufacturer, it was investigated as a method to increase manifold pressure and the amount of NH_3 present in the manifold as liquid.

The Cold−flo® system used a Cold−flo® system 16 #20340 canister and separate 16 outlet distribution manifolds for NH_3 liquid and NH_3 vapor. For the conventional and Cold−flo® manifolds, plugged (unused) outlets were spaced as evenly as possible around the manifold.

For the Cold−flo® manifold, equal lengths of 12.7−mm (0.5−in.) hose were used from the vapor distribution manifold to the vapor inlet on each knife. Because only one set of 11 valve assemblies was available to measure distribution, only the liquid phase of distribution was measured. For all other manifolds, standard 9.5−mm (0.38−in) hoses were used.

Outlet hoses were connected in order sequentially clockwise around each manifold as viewed from above. The outlet for knife one on the left end of the applicator (as viewed from the rear) was always at a position of 0° when viewed from above (0° was the direction of travel).

For the November 1999 experiment the conventional manifold was used with minor modifications. In addition to the design used in the August experiment (straight−entry), the manifold was also used with only a 25.4−mm (1.0−in.) elbow (elbow−entry). The 254−mm (10.0−in.) long nipple was also replaced with a 316 stainless steel nipple of the same length with a Teflon™ coated static flow mixer (Omega part no. FMX8413T) in the nipple (mixer−entry). In addition to the two Vertical−Dam manifolds, a Rotaflow™ (H.I. Fraser Pty Ltd, Sydney, Australia) manifold was added with the 11 outlet ports evenly spaced in the 24 outlet housing.

To compare distribution characteristics within the conventional manifold, a treatment was added with all three blocked ports together on the far side of the manifold across from the direction of the incoming flow (uneven plugs) using the elbow entry conventional manifold. Figure 2 shows some of the manifolds used in the November 1999 experiment. For the November experiment and all subsequent experiments, all tests were run with 11 manifold outlets and knives.

For the spring of 2000, the conventional (elbow−entry) was retained for its use as the "control" manifold due to its widespread use on current applicators. Because of concerns about flow metering due to small orifice size for the small housing Vertical−Dam at the 168−kg N/ha (150−lb N/acre) application rate, this treatment was dropped from subsequent experiments. As a replacement, the large housing (SVD−01) Vertical−Dam was tested using the common 'corn' ring, and the large housing Vertical−Dam with the 'cotton' ring (Continental NH_3 Products #R−152) treatment continued. The 'cotton' ring contained smaller outlet orifices than the 'corn' ring but larger ones than the small housing Vertical−Dam ring.

Two additional manifolds were designed and tested to determine if the radial manifold designs or linear manifolds should be given continued consideration. The side−entry and the tee−entry manifolds were fabricated out of 25.4−mm (1.0−in.) inside diameter aluminum pipe and had 12 outlets spaced 50.8 mm (2.0 in.) on center. Flow entered the pipe from one end or in the middle for the side− and tee−entries, respectively. Each manifold was mounted to the tool bar so that the outlets were vertical with the outlet barbs pointing upward. An FD−1200 prototype (CDS John Blue Co., Huntsville, Ala.) was also tested. The manifold was a prototype and liquid fertilizer manifolds designated FD−1200 cannot withstand NH_3 and should not be used for NH_3 application. The FD−1200 prototype was plumbed with a 19−mm (0.75−in.) straight inlet nipple 254 mm (10.0 in.) long. Manifolds used 11 outlets, and unused ports were evenly distributed around the manifold body.

In November 2000, datalogging equipment was added to measure temperature and pressure. The "control" conventional 3497, Vertical−Dam (small housing, cotton, and corn rings), FD−1200 prototype, and Rotaflow™ were included in the experiment.

Manifolds tested in April 2001 included the Vertical−Dam (small housing and cotton ring), conventional, FD−1200 prototype, and the Equa−Flow™ manifold (PGI International, Houston, Tex.). The Equa−Flow™ manifold had an operator adjustable plunger to adjust back pressure in the manifold by controlling manifold volume. The manufacturer recommended adjustment so that back pressure at the manifold was 60% to 75% of the tank pressure. In addition, the Impellicone manifold, designed by the research group, was tested in two configurations. The Impellicone manifold design had a grooved inverted cone that rotated and distributed NH_3 to 11 radial outlets.

Manifolds evaluated in the November 2001 experiment were the same as in April 2001 with the exception of a slight design modification to the Impellicone manifold.

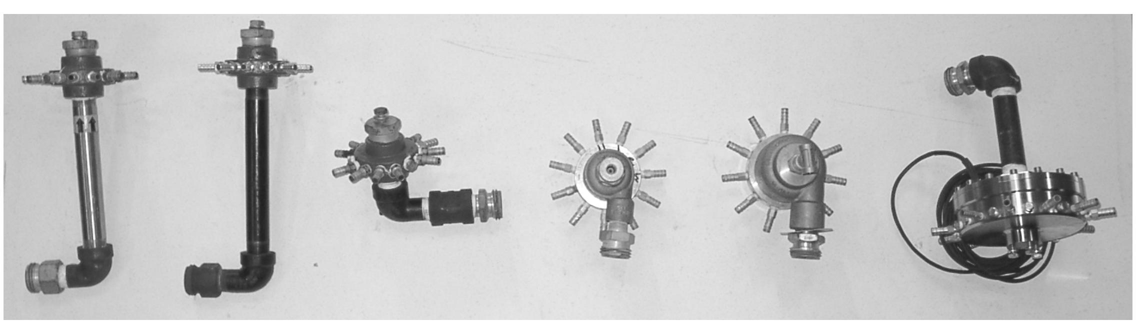

Figure 2. NH_3 manifolds used in the November 1999 experiment. From the left: 3497 w/mixer, 3497 w/nipple, 3497 with elbow, small Vertical−Dam, large Vertical−Dam, and Rotaflow.

In April 2002, the A−6600 manifold (CDS John Blue Co., Huntsville, Ala.) was added to testing. The A−6600 manifold used a rotating outer ring that allowed the area of the outlet orifice to be changed. Testing of the conventional, Equa−Flow™, and the Impellicone manifold continued. Only the Impellicone version #2 was tested. This version had exhibited rotation in the November 2001 experiment. A revised version of the Impellicone #2 is marketed by CDS John Blue Co. under the Impellicone product name. Figure 3 shows five manifolds introduced in the 2000 through 2002 experiments.

Statistical Analysis

Four measures of variability among outlet distribution were computed from the data collected (weight of NH_3 collected in the containers partially filled with water). The average outlet difference was the average absolute difference in kg (lb) NH_3 of all outlets from the mean outlet output for a particular test plot. The average percentage outlet difference was the average of absolute outlet difference from the mean outlet output expressed as a percentage of the mean outlet output. This percentage measure was used to indicate the average percentage each outlet varied from the mean application rate and to normalize variability based on the NH_3 collected during each plot run. High/low ratio was the ratio of the NH_3 weight from the outlet with the greatest output divided by the output from the outlet with the least output for a given plot. Coefficient of variation (CV) among the outlets was also calculated as:

$$CV = (\text{Std. dev./mean}) \times 100\% \qquad (1)$$

and is a common indicator of variation of application across agricultural applicators. To help evaluate overall manifold performance, the range of CV means measured over several experiments was expressed as ΔCV (ΔCV = highest measured CV (%) – lowest measured CV (%)).

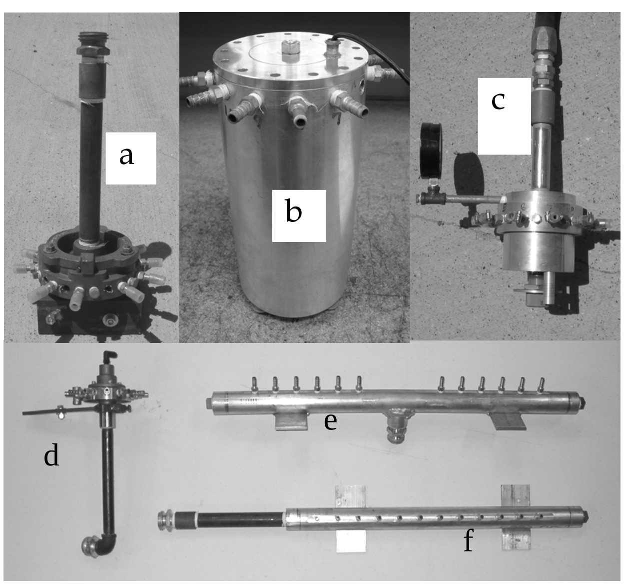

Figure 3. NH_3 manifolds added to the 2000 through 2002 experiments (a) CDS John Blue Co. A−6600, (b) Impellicone, (c) PGI Equa−Flow™, (d) FD−1200 prototype, (e) tee−entry, (f) side−entry.

NH_3 Quality and Distribution

To evaluate the assumption that NH_3 follows the saturation line in the form of a saturated mixture as it moves through the distribution system, comparisons between distribution and material quality were made. Quality is defined as:

$$x = m_{vapor} / m_{total} \qquad (2)$$

where

m_{total} = $m_{liquid} + m_{vapor} = m_f + m_g$
m = mass

If NH_3 follows the saturation line, an adiabatic system with constant enthalpy ($h_1 = h_2 = h_n$) is implied. Constant enthalpy requires that all the energy exchange required for phase change within the NH_3 is provided by the NH_3 itself. To define the points along the flow path in this system, the following designations were assigned:

h_1 = enthalpy of NH_3 at the supply tank
h_1 = $h_{f1} + xh_{fg1}$
xh_{fg1} = 0 (NH_3 is 100% liquid at tank)
h_2 = enthalpy of NH_3 before the regulator
h_2 = $h_1 = h_{f2} + x_2h_{fg2}$
h_3 = enthalpy of NH_3 after the regulator
h_3 = $h_1 = h_{f3} + x_3h_{fg3}$
h_4 = enthalpy of NH_3 at the manifold
h_4 = $h_1 = h_{f4} + x_4h_{fg4}$

where

h_n = total enthalpy (kJ/kg)
h_{fn} = enthalpy of the liquid (kJ/kg)
h_{fgn} = latent heat of vaporization (kJ/kg)
= $h_{gn} - h_{fn}$
x_n = $(h_1 - h_{fn}) / h_{fgn}$ = quality

These equations allowed for the calculation of quality (x) at each point along the flow path. Quality defines the partitioning between the liquid and vapor phases on a mass basis. In addition, using published data for the specific volume of the saturated gas or liquid, the partitioning on a volume basis was calculated with the following equations:

$$x_n = \text{quality} = \text{vapor mass} / (\text{vapor} + \text{liquid mass})$$

$$1 - x_n = \text{liquid mass} / \text{total mass}$$

$$x_n \times sv_g = \text{volume of } NH_3 \text{ in vapor phase}$$

$$(1 - x_n) \times sv_f = \text{volume of } NH_3 \text{ in liquid phase}$$

where

sv_g = specific volume of vapor (m^3/kg)
sv_f = specific volume of liquid (m^3/kg)

$(x_n \times sv_g) / ((x_n \times sv_g) + ((1 - x_n) \times sv_f)) \times 100\%$ = % volume in vapor phase

Quality and volume partitioning of NH_3 through the NH_3 distribution system was calculated for the manifolds used in the November 2000 through April 2002 tests.

Based on concerns in past research that the production and distribution of vapor within the manifold body are factors that may affect manifold distribution, the volume of vapor as a percent of total volume in the manifold was calculated using the equations listed above.

Results and Discussion

The seven experiments conducted resulted in data sets being compiled that included a wide range of field conditions and distribution data for 16 manifold configurations and types.

Early Experiments

Tables 1 through 4 lists the tank and manifold pressures for all manifolds in the August 1999 through November 2000 experiments as well as the average measured application rate and statistical analysis of the experimental results.

Table 1 shows that the application rate appeared low for the Cold−flo® due to the measurement of NH_3 in the liquid phase only. Because of the high variability of flow to the outlet ports and the inability to measure vapor application rates, the Cold−flo® was excluded from later tests. Application rate deviations for all manifolds from the target rate were attributed to regulator settings in the field.

The highest pressures at the manifold were observed with the Vertical−Dam manifolds. The manufacturer (Continental NH_3 Products, Dallas, Tex.) did not design, nor does it recommend the use of the small housing manifold for application rates approaching the 168−kg N/ha (150−lb N/acre) rate. This application was attempted to retain as much pressure as possible at the manifold and keep the amount of NH_3 in the liquid phase high. According to Continental NH_3, pressure at the manifold in excess of 65% of the tank pressure may overly restrict and meter flow through the orifice at the manifold.

No differences in distribution variability were measured when comparing the two outlet configurations (7− and 11−outlets)(Boyd et al., 2000). These results supported the decision to run future experiments at 11 knives only.

Statistical analysis separated the manifolds into two groups. At the lower application rate, the Cold−flo® manifold had a significantly higher CV than the conventional and Vertical−Dam (SH) manifolds ($\alpha = 0.05$). Increasing the application rate yielded similar results with CV, high/low ratio, and percent outlet difference. At the 168−kg N/ha (150−lb N/acre) application rate, the Vertical−Dam (SH) had a much lower average outlet difference than all other manifolds. This lower difference may be attributed to the high manifold pressure or the slightly reduced application rate. The average pressure during the runs was 75% of the tank pressure. Exceeding the pressure ratio guideline may have limited application rate due to the inability of the manifold orifices to allow sufficient flow of NH_3. This metered flow could have resulted in the measured application rate lower than the goal; both the conventional and the Vertical−Dam (cotton) exceeded the application goal.

Table 2 summarizes the experimental results from November 1999. For the Vertical−Dam (SH) in this experiment, the pressure ratio was 79%, well above the recommended ratio. At the lower application rate, the Vertical−Dam (SH) and the Rotaflow™ manifolds performed similarly statistically. Similar trends were seen at the 168−kg N/ha (150−lb N/acre) application rate. The CV dropped by approximately 10 percentage points for most conventional manifold treatments. This trend, also seen in the first experiment suggests that with increased application rate and the resultant higher flow rate of NH_3 through the manifold, variation among outlets may be reduced. At the higher application rate, variability among some of the treatments was diminished. The conventional manifold treatments continued to have the greatest variability at each rate.

Table 3 summarizes the March 2000 experiment. Good uniformity was again observed with the Rotaflow™ and Vertical−Dam (SH) manifold. The Vertical−Dam (Cotton) had significantly lower values than the Vertical−Dam (Corn) in all statistical comparisons except the high/low ratio. The Vertical−Dam (Cotton), with its smaller orifices may cause a restriction and meter flow with application rates at or above the 168−kg N/ha (150−lb N/acre) rate. The corn ring allowed for a higher application rate, but with higher tank pressure. The manifold pressure as a percentage of tank pressure with the Vertical−Dam manifold and the corn ring (59%) was below the critical value (65%) and the cotton ring (75%) was above this limit.

The FD−1200 prototype had low variation at the high application rate but moderate variation at the low application rate. It was not statistically different than the Rotaflow™ at

Table 1. Tank and manifold pressure, NH_3 application rate, and distribution variation during treatments with various manifolds (August 1999).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation, %
84 kg N/ha (75 lb N/acre)							
Conventional	1061 (154)	165 (24)	82 (73)	0.053 (0.116)*ab*	12.4*a*	1.66*a*	16.1*a*
Vertical−Dam (SH)	978 (142)	441 (64)	74 (66)	0.041 (0.091)*a*	10.9*a*	1.47*a*	13.4*a*
Cold−flo®	999 (145)	14 (2)	63 (56)[g]	0.064 (0.141)*b*	19.9*b*	5.18*b*	27.1*b*
168 kg N/ha (150 N lb/acre)							
Conventional	1082 (157)	345 (50)	173 (154)	0.038 (0.083)*b*	8.2*a*	1.39*a*	10.4*a*
Vertical−Dam (Cotton)	971 (141)	496 (72)	182 (162)	0.032 (0.071)*b*	7.5*a*	1.51*a*	9.7*a*
Vertical−Dam (SH)	971 (141)	723 (105)	147 (131)	0.017 (0.037)*a*	4.2*a*	1.21*a*	5.7*a*
Cold−flo®	992 (144)	21 (3)	116 (103)[g]	0.049 (0.107)*b*	15.8*b*	17.59*b*	22.1*b*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum single outlet weight/minimum single outlet weight.
[g] Measured liquid (without vapor) application rate only for Cold−flo®.

Table 2. Tank and manifold pressure, NH_4 application rate, and distribution variation during treatments with various manifolds (November 1999).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation %
84 kg N/ha (75 lb N/acre)							
Conv. elbow−entry	572 (83)	138 (20)	89 (79)	0.096 (0.212)*c*	21.1*c*	2.57*c*	29.6*d*
Conv. mixer−entry	489 (71)	145 (21)	101 (90)	0.102 (0.225)*c*	19.6*c*	2.19*b*	24.7*c*
Conv. straight−entry	482 (70)	138 (20)	103 (92)	0.052 (0.114)*b*	9.7*b*	1.42*a*	11.8*b*
Rotaflow™	448 (65)	131 (19)	106 (94)	0.021 (0.046)*a*	3.8*a*	1.18*a*	4.9*a*
Vertical−Dam (SH)	517 (75)	407 (59)	98 (87)	0.022 (0.048)*a*	4.3*a*	1.20*a*	5.7*a*
Conv. uneven plugs	606 (88)	138 (20)	90 (80)	0.102 (0.225)*c*	22.1*c*	2.25*b*	28.5*d*
168 kg N/ha (150 lb N/acre)							
Conv. elbow−entry	558 (81)	241 (35)	162 (144)	0.062 (0.137)*c*	14.3*d*	1.75*b*	17.6*c*
Conv. mixer−entry	482 (70)	241 (35)	184 (164)	0.059 (0.129)*c*	11.9*cd*	1.61*b*	14.8*bc*
Conv. straight−entry	537 (78)	234 (34)	163 (145)	0.053 (0.116)*c*	11.2*cd*	1.70*b*	15.6*bc*
Rotaflow™	448 (65)	241 (35)	177 (158)	0.013 (0.028)*a*	4.1*a*	1.23*a*	5.7*a*
Vertical−Dam (Cotton)	613 (89)	393 (57)	168 (150)	0.037 (0.082)*b*	9.7*bc*	1.47*ab*	11.7*b*
Vertical−Dam (SH)	586 (85)	510 (74)	118 (105)	0.020 (0.044)*a*	6.4*ab*	1.32*a*	8.3*ab*
Conv. uneven plugs	467 (68)	255 (37)	191 (170)	0.059 (0.130)*c*	11.5*cd*	1.59*b*	14.1*bc*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

the high rate, but was grouped with the conventional manifold at the low rate.

Application with the Side Entry and Tee Entry linear manifolds resulted in greater variation between outlets than any other manifolds tested. Liquid flow moved to the farthest outlet away from the inlet point. Distribution of linear manifolds from the outlet closest to the entry point to the furthest outlet on both manifolds yielded high/low ratios that exceeded 5.7, the equivalent of application rates between 60 and 350 kg N/ha (54 to 313 lb N/acre). Radial manifolds had better distribution than both linear manifolds. This performance resulted in the elimination of the two linear manifolds from future tests.

Table 4 summarizes the results of the November 2000 experiment. Both the cotton and corn ring Vertical−Dam manifolds performed better than in March 2000 with similar manifold pressures and slightly lower application rates. The FD−1200 prototype and the Rotaflow™ did not perform as well at the high flow rate.

Table 3. Tank and manifold pressure, NH_3 application rate, and distribution variation during treatments with various manifolds (March 2000).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation %
84 kg N/ha (75 lb N/acre)							
Side Entry	400 (58)	117 (17)	106 (94)	0.395 (0.869)*c*	66.0*c*	7.34*b*	74.5*c*
Tee Entry	407 (59)	110 (16)	107 (95)	0.392 (0.862)*c*	70.8*c*	8.64*b*	80.5*c*
Conventional	317 (46)	145 (21)	116 (103)	0.095 (0.210)*b*	16.3*b*	1.99*a*	22.3*b*
Vertical−Dam (SH)	345 (50)	282 (41)	94 (84)	0.025 (0.054)*a*	5.1*a*	1.20*a*	6.0*a*
FD−1200	400 (58)	158 (23)	108 (96)	0.071 (0.156)*b*	12.4*b*	1.96*a*	19.1*b*
Rotaflow™	420 (61)	138 (20)	104 (93)	0.028 (0.061)*a*	5.2*a*	1.24*a*	6.7*a*
168 kg N/ha (150 lb N/acre)							
Side Entry	386 (56)	200 (29)	199 (177)	0.312 (0.686)*d*	58.4*f*	7.05*b*	65.7*e*
Tee Entry	413 (60)	220 (32)	203 (181)	0.276 (0.608)*c*	50.5*e*	5.70*b*	59.2*e*
Conventional	551 (80)	282 (41)	191 (170)	0.068 (0.149)*b*	13.2*cd*	1.66*a*	16.0*c*
Vertical−Dam (Corn)	441 (64)	262 (38)	179 (159)	0.085 (0.188)*b*	16.0*d*	2.74*a*	27.5*d*
Vertical−Dam (Cotton)	351 (51)	262 (38)	158 (141)	0.041 (0.090)*a*	9.8*bc*	2.55*a*	15.0*bc*
FD−1200	400 (58)	248 (36)	174 (155)	0.025 (0.056)*a*	5.5*ab*	1.24*a*	6.7*ab*
Rotaflow™	420 (61)	248 (36)	197 (175)	0.022 (0.048)*a*	4.2*a*	1.21*a*	5.4*a*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average lbs NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

Table 4. Tank and manifold pressure, application rate, and distribution variation during treatments with various manifolds (November 2000).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation, %
84 kg N/ha (75 lb N/acre)							
Vertical−Dam (SH)	358 (52)	200 (29)	81 (71)	0.020 (0.044)*a*	4.9a	1.19*a*	5.9*a*
Conventional	400 (58)	117 (17)	91 (81)	0.079 (0.173)*b*	14.6*b*	2.17*c*	22.8*b*
FD−1200	351 (51)	145 (21)	85 (76)	0.061 (0.134)*b*	14.5*b*	1.81*b*	19.0*b*
Rotaflow™	338 (49)	110 (16)	93 (83)	0.019 (0.042)*a*	4.0*a*	1.17*a*	5.0*a*
168 kg N/ha (150 lb N/acre)							
Vertical−Dam (Cotton)	386 (56)	227 (33)	148 (132)	0.016 (0.036)*a*	4.1*a*	1.12*a*	5.4*a*
Vertical−Dam (Corn)	386 (56)	179 (26)	147 (131)	0.033 (0.073)*b*	8.4*ab*	1.37*ab*	10.3*ab*
Conventional	400 (58)	193 (28)	157 (140)	0.060 (0.113)*c*	12.0*b*	1.71*c*	17.0*c*
FD−1200	351 (51)	200 (29)	143 (127)	0.040 (0.089)*bc*	10.5*b*	1.52*bc*	13.8*bc*
Rotaflow™	331 (48)	152 (22)	133 (118)	0.021 (0.046)*a*	6.0*a*	1.36*ab*	8.2*ab*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Gage Pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

Late Experiments with New and Modified Manifolds

Table 5 summarizes the April 2001 experiment results. The initial version of the Impellicone was tested during the April 2001 experiment, but failed to rotate as designed. The result was very poor distribution, and the results for the Impellicone were omitted in the statistical analysis since including the Impellicone would have drastically affected the statistical grouping of the other manifolds tested. Results for the Vertical−Dam, conventional, and FD−1200 prototype manifolds were consistent with earlier experiments. The Equa−flow™ manifold produced the lowest variation, with an average CV across both application rates of 6.0%.

The third experiment with the FD−1200 prototype manifold, in November 2001, produced similar results to earlier experiments (table 6). Distribution variation increased at both application rates for the Equa−flow™ manifold. An attempt was made to achieve the pressure ratio with the Equa−flow™ as close to the manufacturers recommendation as possible. Due to a calibration error, the Equa−flow™ was tested with a manifold to tank pressure ratio of 17% for the lower application rate, and 36% for the higher rate. Gage error may have been responsible for pressure ratios below the specified range. With the pressure ratio well below the recommended level, the Equa−flow™ placed in the second statistical grouping. Increasing the pressure ratio to the recommended level may result in lower CV values.

Modifications to the Impellicone design during the summer of 2001 resulted in two manifold impeller designs. Impellicone #2 and #3 were tested during the November 2001 experiment. Impellicone #2 placed in the top statistical category at both application rates. The attached tachometer measured fairly constant rotation of the impeller. Impellicone #3 operated well at the lower application rate but was one of the worst performers of all the manifolds tested at the higher application rate. The tachometer measured only occasional pulses of rotation within the manifold.

The experiment in April 2002 was conducted in cold air temperatures (−2°C to 4°C (28°F to 39°F)] and generally had the lowest values of distribution variation (table 7). The Equa−flow™, while tested with a manifold pressure that was

Table 5. Tank and manifold pressure, NH_3 application rate, and distribution variation during treatments with various manifolds (April 2001).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation, %
84 kg N/ha (75 lb N/acre)							
Vertical−Dam (SH)	730 (106)	338 (49)	85 (76)	0.041 (0.091)*b*	9.5*b*	1.54*b*	12.6*c*
Conventional	827 (120)	145 (21)	77 (69)	0.080 (0.176)*c*	20.1*c*	2.26*c*	25.9*d*
FD−1200	661 (96)	172 (25)	91 (81)	0.039 (0.086)*b*	8.3*b*	1.14*a*	9.8*b*
Equa−Flow™	675 (98)	469 (68)	92 (82)	0.020 (0.045)*a*	4.3*a*	1.26*a*	6.1*a*
168 kg N/ha (150 lb N/acre)							
Vertical−Dam (Cotton)	689 (100)	400 (58)	171 (152)	0.038 (0.084)*b*	8.3*b*	1.38*a*	10.5*b*
Conventional	834 (121)	331 (48)	170 (151)	0.059 (0.130)*c*	13.0*c*	1.95*b*	19.1*c*
FD−1200	675 (98)	331 (48)	177 (158)	0.033 (0.072)*b*	6.9*b*	1.44*a*	9.9*b*
Equa−Flow™	675 (98)	462 (67)	177 (158)	0.019 (0.041)*a*	3.9*a*	1.22*a*	5.8*a*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

Table 6. Tank and manifold pressure, NH_3 application rate, and distribution variation during treatments with various manifolds (November 2001).[a]

Treatment	Tank Pressure[b] kpa (psi)	Manifold Pressure[b] kpa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation %
84 kg N/ha (75 lb N/acre)							
Vertical−Dam (SH)	758 (110)	345 (50)	99 (88)	0.032 (0.071)*a*	6.4*ab*	1.33*a*	8.5*ab*
Conventional	744 (108)	172 (25)	101 (90)	0.070 (0.153)*c*	13.3*c*	1.91*c*	18.9*d*
FD−1200	758 (110)	193 (28)	99 (88)	0.047 (0.103)*b*	9.2*b*	1.48*b*	12.1*c*
Equa−Flow™	758 (110)	131 (19)	69 (61)	0.028 (0.062)*a*	7.9*b*	1.44*b*	10.6*bc*
Impellicone #2	688 (97)	172 (25)	102 (91)	0.024 (0.053)*a*	4.6*a*	1.18*a*	5.5*a*
Impellicone #3	688 (97)	179 (26)	100 (89)	0.035 (0.077)*ab*	6.7*a*	1.33*a*	8.6*ab*
168 kg N/ha (150 lb N/acre)							
Vertical−Dam (Cotton)	688 (97)	338 (49)	192 (171)	0.020 (0.044)*a*	3.9*a*	1.20*a*	5.3*a*
Conventional	723 (105)	282 (41)	169 (151)	0.051 (0.112)*b*	11.2*c*	1.96*c*	17.2*c*
FD−1200	758 (110)	331 (48)	185 (165)	0.030 (0.067)*a*	6.1*ab*	1.26*a*	7.5*ab*
Equa−Flow™	758 (110)	276 (40)	143 (127)	0.030 (0.065)*a*	7.7*b*	1.30*a*	9.1*b*
Impellicone #2	688 (97)	269 (39)	180 (160)	0.021 (0.046)*a*	4.3*a*	1.27*a*	6.2*ab*
Impellicone #3	655 (95)	324 (47)	198 (176)	0.090 (0.198)*c*	15.9*d*	1.74*b*	19.0*c*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the α = 0.05 level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

only 43% of tank pressure at the lower application rate, produced a relatively low CV of 4.0%. At the high application rate and 65% of tank pressure, the manifold had a CV of 3.2%; the lowest value recorded in all experiments.

The Impellicone #2 manifold produced a slightly higher CV for the lower application rate and the identical CV at the higher application rate as it had in the November 2001 experiment. Performance of the A−6600 was similar to the conventional at the lower application rate and between the conventional and the group including all other manifolds at the higher application rate.

Overall Manifold Performance

The statistical results from each experiment were combined for each manifold that was tested in more than one experiment. This was done to examine if overall differences could be observed (table 8).

The conventional and Vertical−Dam (SH vs. Cotton) comparisons used data from seven experiments. The FD−1200 prototype comparison used four experiments of data, while the Equa−Flow™, Rotaflow™, and Vertical−Dam (SH vs. Corn) used data from three experiments. Two experiments were used to evaluate the Impellicone manifold.

Table 7. Tank and manifold pressure, NH_3 application rate, and distribution variation during treatments with various manifolds (April 2002).[a]

Treatment	Tank Pressure[b] kPa (psi)	Manifold Pressure[b] kPa (psi)	N Application Rate[c] kg/ha (lb/acre)	Avg. Outlet Difference, NH_3[d] kg (lb)	Avg. % Outlet Difference[e]	High/Low Ratio[f]	Coefficient of Variation, %
84 kg N/ha (75 lb N/acre)							
Vertical−Dam (SH)	282 (41)	234 (34)	91 (81)	0.029 (0.063)*b*	6.2*b*	1.37*c*	5.7*ab*
Conventional	269 (39)	124 (18)	99 (88)	0.060 (0.133)*c*	11.8*c*	1.96*e*	18.7*c*
A−6600	269 (39)	179 (26)	99 (88)	0.078 (0.171)*d*	15.3*d*	1.56*d*	17.4*c*
Equa−Flow™	317 (46)	138 (20)	98 (87)	0.016 (0.035)*a*	3.2*a*	1.14*a*	4.0*a*
Impellicone #2	338 (49)	138 (20)	97 (86)	0.029 (0.064)*b*	5.8*b*	1.26*b*	7.3*b*
168 kg N/ha (150 lb N/acre)							
Vertical−Dam (cotton)	282 (41)	241 (35)	159 (142)	0.012 (0.027)*ab*	2.8*a*	1.14*ab*	4.0*ab*
Vertical−Dam (corn)	303 (44)	220 (32)	168 (150)	0.030 (0.065)*c*	6.6*c*	1.27*c*	7.9*c*
Conventional	269 (39)	186 (27)	163 (145)	0.050 (0.110)*e*	11.5*e*	1.91*d*	16.2*e*
A−6600	276 (40)	241 (35)	163 (145)	0.040 (0.088)*d*	8.7*d*	1.33*c*	10.1*d*
Equa−Flow™	317 (46)	207 (30)	157 (140)	0.011 (0.024)*a*	2.5*a*	1.12*a*	3.2*a*
Impellicone #2	324 (47)	207 (30)	157 (140)	0.020 (0.043)*b*	4.7*b*	1.24*bc*	6.2*bc*

[a] Values in each column within each rate followed by a different *italic* letter are significant at the α = 0.05 level.
[b] Gage pressure.
[c] Application rate as measured into collection buckets.
[d] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[e] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[f] High/low ratio = maximum outlet weight/minimum outlet weight.

Table 8. NH_3 distribution variation at two application rates within manifold types.[a]

Manifold	N Application Rate Goal kg/ha (lb/acre)	Avg. Outlet Difference kg (lb)[b]	Avg. % Outlet Difference[c]	High/Low Ratio[d]	Coefficient of Variation (CV) %
Conventional	84 (75)	0.076 (0.168)*a*	15.6*a*	2.07*a*	22.0*a*
Conventional	168 (150)	0.054 (0.119)*b*	11.9*b*	1.76*b*	16.2*b*
Equa−Flow™	84 (75)	0.021 (0.047)	5.1	1.28	6.9
Equa−flow™	168 (150)	0.020 (0.043)	4.7	1.23	6.0
Rotaflow™	84 (75)	0.019 (0.041)	4.3	1.20	5.5
Rotaflow™	168 (150)	0.023 (0.050)	4.8	1.27	6.3
FD−1200 prototype	84 (75)	0.057 (0.125)	11.7	1.60	15.2
FD−1200 prototype	168 (150)	0.033 (0.072)	7.3	1.37	9.5
Vertical−Dam (SH)	84 (75)	0.030 (0.066)	6.7	1.33	8.3
Vertical−Dam (corn)	168 (150)	0.050 (0.109)	10.3	1.79	15.2
Vertical−Dam (SH)	84 (75)	0.030 (0.066)	6.7	1.33	8.3
Vertical−Dam (cotton)	168 (150)	0.028 (0.062)	6.6	1.48	8.8
Impellicone #2	84 (75)	0.027 (0.059)	5.2	1.22	6.4
Impellicone #2	84 (75)	0.021 (0.045)	4.5	1.26	6.2

[a] Values in each column within each manifold followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.
[b] Average kg (lb) NH_3 difference of an outlet from mean of outlets.
[c] Average difference of outlet from mean of outlets expressed as a percentage of mean.
[d] High/low ratio = maximum single outlet weight/minimum single outlet weight.

The average CV was calculated for each manifold as the composite of all replications from all experiments during which the manifold was used. The results of the CV calculation were used as an indicator of manifold performance, as the grouping of manifolds based on CV was usually identical to the grouping dictated by other factors.

Only the conventional manifold showed a statistical difference in distribution variation between application rates when comparing within the manifold model. A comparison using CV across manifolds at each application rate indicated that the conventional manifold was significantly different than all the other manifolds at the 84−kg N/ha (75−lb N/acre) application rate, and grouped with the Vertical−Dam (Corn) and the FD−1200 prototype at the 168−kg N/ha (150−lb N/acre) application rate. Overall manifold performance could be separated into three groups based on statistical results. Manifold distribution performance was categorized as poor, moderate, and good, based on subjective observation of the manifolds that are currently available and those under development (tables 9 and 10).

At the 168−kg N/ha (150−lb N/acre) application rate (table 9), the conventional manifold had a consistently poor CV of 16.2%, but variation of the CV value between experiments never exceeded 8.7 percentage points. The Vertical−Dam (Corn) manifold produced a CV of 7.9% during the April 2002 experiment, but the average CV was affected by greater variation in other experiments and the maximum ΔCV [ΔCV = highest measured CV (%) – lowest measured CV (%)] was 19.6%. The manifolds grouped into the moderate range produced lower distribution variation than the poor group. The FD−1200 prototype performed at a level in the middle of the group of manifolds tested (table 9). The average CV and ΔCV for the FD−1200 prototype were grouped between all other manifolds. The Vertical−Dam (Cotton) manifold produced CV values between 4.0% and 15%. The lack of consistency with the Vertical−Dam (Cotton) manifold prevented its inclusion in the group of top performers.

Between the three manifolds in the good category (table 9), the Equa−flow™ had the highest ΔCV, but manifold pressures were not always in the optimum range during operation. The Impellicone #2 produced a ΔCV of 0.0% with testing in two experiments. The Vertical−Dam (SH) was not included in the results in table 9 because while it performed well, its inability to meet the application rate goal does not make it a viable alternative for application at this rate.

Table 9. Overall manifold performance at NH_3 application rate of 168 kg N/ha (150 lb N/acre).[a]

Manifold	Average CV, %	Performance Group	Max. ΔCV Among Experiments, %
Conventional	16.2*a*	Poor	8.7
Vertical−Dam (Corn)	15.2*ab*	Poor	19.6
FD−1200 prototype	9.5*abc*	Moderate	7.1
Vertical−Dam (Cotton)	8.8*c*	Moderate	11.0
Rotaflow™	6.3*c*	Good	2.8
Impellicone #2	6.2*c*	Good	0.0
Equa−flow™	6.0*c*	Good	5.9

[a] Values followed by a different *italic* letter are significant at the $\alpha = 0.05$ level

A similar evaluation of results at the 84−kg N/ha (75−lb N/acre) rate is shown in table 10. Manifold rankings were similar to those at the higher application rate, except the performance of the Vertical−Dam (SH) manifold placed it in the top group.

While only the conventional manifold had a statistically lower CV at the high rate than at the low application rate, manifold CV dropped with the increase in application rate for most manifolds tested. Exceptions to this were the Rotaflow manifold, which produced a CV of 5.5% at 84 kg N/ha

Table 10. Overall manifold performance at NH_3 application rate of 84 kg N/ha (75 lb N/acre).[a]

Manifold	Average CV, %	Performance Group	Max. ΔCV Among Experiments, %
Conventional	22.0*a*	Poor	13.5
FD−1200 prototype	15.0*b*	Moderate	9.3
Vertical−Dam (SH)	8.3*c*	Good	7.7
Equa−flow™	6.9*c*	Good	6.6
Impellicone #2	6.4*c*	Good	1.8
Rotaflow™	5.5*c*	Good	1.8

[a] Values followed by a different *italic* letter are significant at the $\alpha = 0.05$ level.

(75 lb N/acre) and 6.3% at 168 kg N/ha (150 lb N/acre), and the Vertical−Dam, which produced a CV of 8.3% for the Vertical−Dam (SH), and 15.2% and 8.8% for the Vertical−Dam (Corn) and Vertical−Dam (Cotton), respectively.

Any of the manifolds producing CV values below 10% would increase application uniformity beyond use of a conventional−type manifold. The Vertical−Dam manifolds (Cotton and SH) would be the least expensive solutions but may not provide the best available distribution. For producers currently using a large housing Vertical−Dam with the corn ring, a change to the cotton ring may reduce application variation if application rates do not exceed the 168−kg N/ha (150−lb N/acre) range, the equivalent of 254 kg N/h/outlet (227 lb N/h/outlet), and manifold pressure is monitored.

As occurred during the experiments, manifolds that need to be adjusted by the operator introduce the possibility of adjustment error. This error is also possible with the Vertical−Dam manifolds with the improper outlet ring for the desired application rate. Manifolds that did not require operator adjustment were the easiest to configure.

Temperature and Pressure of NH_3 within the Applicator

As the NH_3 flowed through the system, flow restrictions due to the regulator and line friction caused reduction in line pressure, which resulted in lower mixture temperature as the NH_3 stayed at or near saturation. Temperature and pressure values, collected at 1−s intervals, were used to evaluate whether NH_3 acted as a saturated mixture as it moved through the distribution system.

The collected data points were grouped by manifold in an attempt to detect any trends and anomalies in the results. Figure 4 shows typical temperature and pressure data compiled for the FD−1200 prototype, tested in multiple experiments. Each symbol represents three data points for the replications of each treatment.

The saturation line (Sonntag and Van Wylen, 1982) separating liquid and vapor phases, identifies the conditions at which NH_3 changes phase. NH_3 will be a liquid above and to the left of the line, and a vapor below and to the right of the line. A change in enthalpy, the internal energy of NH_3, is required to move NH_3 away from the saturation line.

Figure 4 shows that as the NH_3 material moves through the system, the temperature and pressure both decrease. For after regulator and manifold data points, the grouping of three data points lower on the line were collected at the 84−kg N/ha (75−lb N/acre) application rate, and the higher three points at the 168−kg N/ha (150−lb N/acre) rate. These changes in pressure can be seen when looking at the pressure data in the experiment summary tables one through seven.

To correlate the measured data to the saturation line, a linear correlation was evaluated. The measured pressure at each recorded temperature was plotted against the theoretical pressure calculated from the saturation line. In reference to the FD−1200 prototype in figure 4, 99.3% of the variation in the measured pressure reading could be explained by the theoretical pressure (i.e. assumption of saturated conditions) at any given temperature.

Table 11 lists the statistical results for each manifold tested between November 2000 and April 2002 evaluated for correlation between actual data and the theoretical saturation line.

The standard error of prediction (SEP) was calculated as the standard deviation of the residuals between the theoretical pressure and the measured pressure. In terms of the conventional manifold, the SEP states that the actual pressure would be within ±16.1 kPa (2.3 psi) of the theoretical pressure during 68% (one standard deviation) of the measurements.

NH_3 conditions in the liquid phase of the saturation diagram would require compression of NH_3 or a loss in temperature due to a thermal sink. As differential pressure

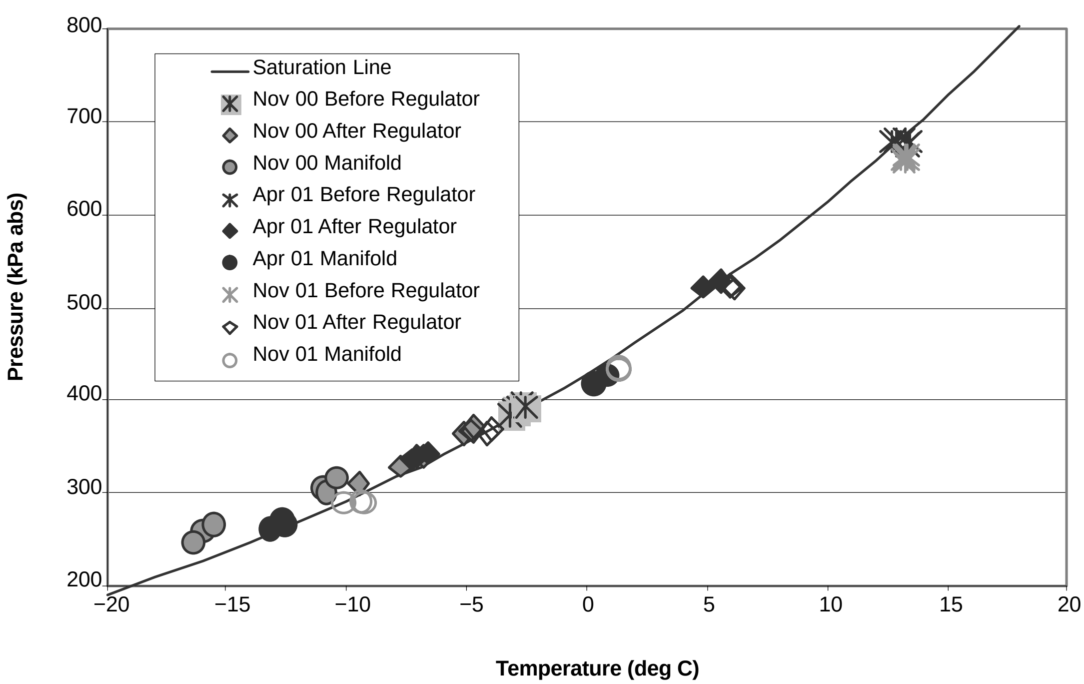

Figure 4. NH_3 temperature and pressure data for the FD−1200 manifold in comparison to the saturated condition.

Table 11. Statistical analysis of temperature and pressure data for correlation with the theoretical saturation line for NH_3.

Manifold	Slope of Best Fit Linear Line	Degrees of Freedom	R^2	Std. Error of Pred. (SEP), kPa
Conventional	0.9405	61	0.996	±16.1
FD−1200 prototype	0.9260	49	0.993	±16.6
Equa−flow™	0.9837	40	0.991	±15.8
Rotaflow™	0.8082	16	0.984	±17.3
A−6600	0.6123	16	0.893	±30.6
Impellicone #2	0.8837	16	0.997	±12.1

moves NH_3 through the applicator no external source of compression was evident. During all of the experiments, the air temperature was higher than the temperature of the manifold. Without thermal energy sinks or external pressure sources available to drive NH_3 to a fully saturated liquid, the data points for the manifolds showing NH_3 as a supercooled liquid are unexpected. The three manifolds with the largest data sets resulted in very good correlations, slopes near 1.0, and SEP values less than ±16.6 kPa (2.3 psi). Overall variations between observed and predicted values were small.

Based on these data sets, NH_3 in a fertilizer application system including a tank, hoses, regulator, and manifold, acts as a saturated mixture as the pressure drops through the system. Material quality and vapor production can be predicted using the established saturation data using actual temperature and pressure of NH_3.

It was hypothesized that the percentage of volume in vapor in the manifold may be related to distribution. Possible comparisons could be between CV, air temperature, and quality or vapor partitioning. The manifolds were separated into two groups: those with fixed volume cavities, including the conventional, Vertical−Dam, and the Impellicone, versus those with variable volume cavities, including the FD−1200 prototype and the Equa−flow™ manifold.

Only the conventional manifold at the 84−kg N/ha (75−lb N/acre) rate showed any observed trend between CV and NH_3 volume in vapor, that of increasing CV with increasing NH_3 volume in vapor (fig. 5). This trend is only observed by plotting data, as statistical analysis failed to show significant difference between any trendline and a line of slope = 0. Also, a general trend apparent in figure 5 was increased CV with higher air temperatures. While this interaction may have some effect on variation, statistical analysis failed to show a slope significantly different than zero (α = 0.05)

CONCLUSIONS AND RECOMMENDATIONS

The seven experiments performed allowed a comprehensive look at NH_3 distribution performance of 16 different manifold configurations. The number of evenly spaced outlets around a radial manifold did not have a significant effect on distribution (August 1999). The testing of the side−entry and tee−entry manifolds in March 2000 indicated distribution variation with the linear manifolds was greater than any of the radial manifolds by a factor of at least two.

Results from testing the conventional and Vertical−Dam manifolds indicate:

- The conventional manifold consistently had the poorest uniformity. Distribution uniformity was statistically better at the 168−kg N/ha (150−lb N/acre) rate than at the 84−kg N/ha (75−lb N/acre) rate for the conventional manifold, and it had statistically worse variation than all Vertical−Dam manifolds except the Vertical−Dam (Corn) at the 168−kg N/ha (150−lb N/acre) rate.
- The Vertical−Dam (Cotton) had more uniform NH3 distribution than the conventional manifold and the Vertical−Dam (Corn) manifold at the 168−kg N/ha (150−lb N/acre) rate. The Vertical−Dam (SH) had good uniformity at the 168−kg N/ha (150−lb N/acre) application rate but did not meet the application goal because of metered flow in the manifold.

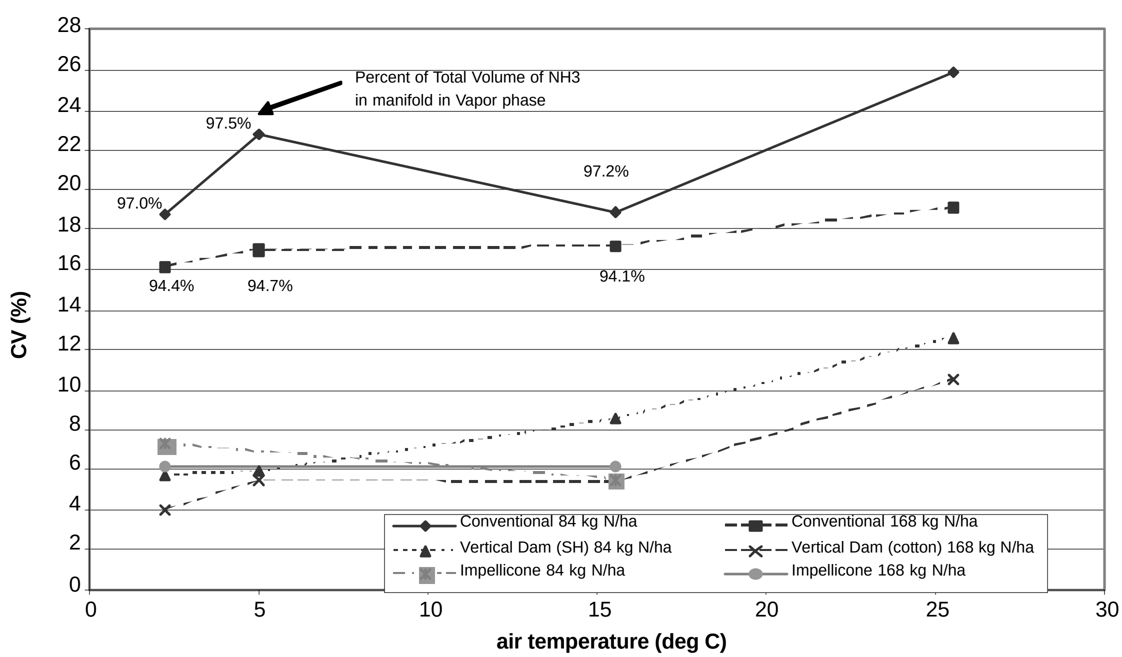

Figure 5. CV vs. air temperature for fixed volume cavity NH_3 manifolds.

A modification of the conventional manifold with an elbow adjacent to the manifold to direct incoming flow was the addition of a 30.5−cm (10.0−in.) pipe nipple below the manifold. This reduced the coefficient of variation by 18 percentage points at the 84−kg N/ha (75−lb N/acre) rate and by 2 percentage points at the 168−kg N/ha (150−lb N/acre) rate. The addition of a similar nipple with a mixer helix inside the pipe did not improve performance over adding the nipple alone. Current users of the conventional manifold may consider the addition of a pipe nipple below the manifold to straighten incoming flow.

The test group including the Rotaflow™, Equa−flow™, and FD−1200 prototype showed:

- The Rotaflow™, Equa−flow™, and FD−1200 prototype manifolds had significantly lower variation in distribution than the conventional manifold at the 84−kg N/ha (75−lb N/acre) application rate, but only the Rotaflow™ and Equa−flow™ were lower than the conventional manifold at the 168−kg N/ha (150−lb N/acre) application rate.
- The Rotaflow™ and Equa−flow™ manifolds had similar uniformity to the Vertical−Dam (SH and Cotton) and better uniformity than the Vertical−Dam (Corn).

Examining all the manifolds as a group across all experiments, only the conventional manifold had statistically higher distribution variation at the 84−kg N/ha (75−lb N/acre) application rate than at the 168−kg N/ha (150−lb N/acre) rate.

The measurement of temperature and pressure along the flow path indicated that NH_3 remains saturated as it moves through the system. Linear analysis of the theoretical pressure as predicted by the saturated condition against the measured pressure resulted in slopes very near one for most manifolds. These results support the assumption that NH_3 follows the saturation line as it moves through the application system, and predictions of vapor partitioning based on theoretical saturation would give a reasonable representation of the actual temperature and pressure. Examination of temperature and pressure data for a correlation between CV, air temperature, and percent volume in the vapor phase failed to produce any statistically significant correlation but did show an observed trend toward increased CV with an increase in percent volume in vapor.

The evolution of new manifolds has decreased the variability in application by nearly four times (CV of 22% for conventional at 84 kg N/ha versus new designs at approximately 6% CV). The adoption of manifolds with CV's of less than 10% could allow reduced application rates of NH_3 by excluding the "insurance" application.

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